PROPERTIES AND BOND BEHAVIOR OF SELF-COMPACTING CONCRETE (SCC)

خواص الخرسانة ذاتية الدمك وسلوك تماسكها مع حديد التسليح

Heniegal, A.M.& Fahmy ,W.S..
Dept. of civil structures, Faculty of Industrial Education, Suez Canal Univ., Suez, EGYPT.

خلاصة:
بدات مشكلة متانة الخرسانة تاخذ كثيرا من اهتمامنا فى السنوات الأخيرة حيث أن هذه المشكلة قد لاقت قدرا كبيرا من الاهتمام و الدراسة. و حيث أن هذه النوعية من الخرسانة تتطلب دمكا كافيا من قبل العمالة الماهرة وان ندرة هذه النوعية من العمالة قد تؤدى الى قلة كفاءة الإنشاءات الخرسانية و كذلك الى ضياع كثير من الوقت المستغرق فى الدمك و التكلفة المحسوبة فى عملية الترميم بعد فك الشدة. كان ظهور اول نموذج للخرسانة الذاتية الدمك قد اكتمل منذ عام ١٩٨٨ وذلك باستخدام المواد الموجودة بالفعل فى ذلك الحين.

ان عامل الجودة و كثافة الغطاء الخرسانى و كذلك دمك الخرسانة من أهم العوامل التى يجب ان تحظى باهتمامنا اذا ما أخذت الاقتصادية و المتانة كثيرا من اهتمامنا. و لهذا فان الخرسانة الذاتية الدمك قد تتيح لنا خواصا و استخدامات جديدة للخرسانة. واظهرت الدراسة ان تصميم الخلطات الخرسانية للخرسانة ذاتية الدمك تختلف عن مثيلتها من الخرسانة ذات الدمك العادى؛ لذا فانه من الضرورى دراسة الخواص الميكانيكية للخرسانة ذاتية الدمك قبل استخدامها فى التطبيقات المختلفة و خصوصا اذا احتاج الأمر الى اعادة النظر فى تصميم الخلطة الخرسانية الذاتية الدمك قبل استخدامها للغرض المحدده له. يهدف هذا البحث الى دراسة خواص الخرسانة ذاتية الدمك و مكوناتها بالإضافة الى سلوك قوة التماسك بين حديد التسليح و الخرسانة ذاتية الدمك.

ABSTRACT

Considering the economy and the durability of our present concrete structures. the quality and the density of the concrete cover, as well as the compaction of the concrete are main parameters. For this, Self-Compacting Concrete (SCC) offers new possibilities and prospects. As a result of the mix design, some properties of the hardened concrete can be different for SCC in comparison to normal vibrated concrete (NC). Therefore, it is important to verify the mechanical properties of SCC before using it for practical applications, especially if the present design rules are applicable or if they need some modifications.

The following paper reports on a research project on the time development of the material properties and the bond behaviour between the reinforcing bars and the self-compacting concrete as basis for the description of the load bearing capacity of reinforced concrete structures.

1 INTRODUCTION

For several years, the problem of the durability of concrete structures was a major topic of interest. The creation of durable concrete structures requires adequate compaction by skilled workers. However, the graduate reduction in the number of skilled workers leads to a reduction in the quality of construction and a waste cost and time for vibrating and repairing concrete after hardening. The prototype of self compacting concrete was first completed in 1988 using materials already in the market.

Since then, several investigations have been carried out to achieve a rational mix design for a standard concrete, which is comparable to normal concrete. Self-compacting concrete is defined so that no

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additional inner or outer vibration is necessary for the compaction. SCC is compacting itself alone due to its self-weight and is deaerated almost completely while flowing in the formwork. In structural members with high percentage of reinforcement it fills also completely all voids and gaps. SCC flows like "honey" and has nearly a horizontal concrete level after placing. With regard to its composition, self-compacting concrete consists of the same components as conventionally vibrated normal concrete, which are cement, aggregates, water, additives and admixtures. However, the high amount of superplasticizer

for reduction of the liquid limit and for better workability, the high powder content as "lubricant" for the coarse aggregates, as well as the use of viscosity-agents to increase the viscosity of the concrete have to be taken into account. In principle, the properties of the fresh and hardened SCC, which depend

on the mix design, should not be different from NC. One exception is only the consistency. Self-compacting concrete should have a slump flow s_f of approx. $s_f >$ 65 cm after pulling the flow cone. Fig. (1) shows the basic principles for the production of SCC.

The present procedure for the production of self-compacting concrete is predominantly empirical. The mix design is based on experience from Japan, the Netherlands, France and Sweden. For the production of SCC, the mix design should be performed so, that the predefined properties of the fresh and hardened concrete are reached for sure. The components shall be coordinated one by one so that segregation, bleeding and sedimentation is prevented.

Fig. (2) shows the present rule for the mix design of SCC (Powder-Type).

2 FACTORS OF SCC IN TERMS OF TESTING RESULTS

2.1 Role Of Coarse Aggregate In SCC

it is not always possible to predict the degree of compaction into a structure by using the test result on the degree of compaction of the concrete into another structure, since the maximum size of coarse aggregate is close to the minimum spacing between reinforcing bars of the structure. The box type test was shown in Fig. (3) is used to measure the self compactability of fresh concrete and the relationship between coarse aggregate content and the filling height of box type test was shown in Fig. (4). The relationship between the filling height through narrow obstacle R1 and that through wide obstacle R2 varied depending on the coarse aggregate content.

2.2 Role Of mortar In SCC

the mortar in SCC plays a role as solid particles. this property is so-called "pressure transferability", which can be apparent when the coarse aggregate particles is subjected to normal stresses. The differences in the relationships between the funnel speed and concrete due to differences in mortar are shown in Fig.(5). It was found that the relationship between the flowability of mortar and concrete cannot always be unique due to differences in the characteristics of the solid particles in the mortar, even if the characteristics of the coarse aggregate and its content in concrete are constant.

A simple evaluation method or the stress transferability of mortar was proposed by using the ratio of the funnel speed of concrete with glass bead as standard coarse aggregate (Rcs) to the speed of mortar (Rm) as shown in Fig. (6) [6].

3 BOND BEHAVIOUR

The load bearing capacity of a reinforced concrete structure is considerably influenced by the bond behaviour between the reinforcing bars and the concrete. Therefore, the following items are mentionable:

- anchorage of the reinforcing bars
- crack width control
- lapped reinforcing bars
- rotation capacity of the concrete structures

For this reason, a systematic investigation on the bond behaviour between the rebars and the SCC is necessary, especially considering the time development of the bond strength. For the bond behaviour of the rebars in normal concrete several investigations were done. From these was found, that the main parameters which have an influence on the bond behaviour are the surface of the rebars, the number of load cycles, the mix design, the direction of concreting, as well as the geometry of the test specimens (pull-out test). From experiments one gains a relation between the bond stresses and the corresponding slip displacements results Fig. (7). From the measured bond stress-slip relationships local bond stress-slip models to calculate the bond stresses as function of the relative displacements can be derived.

The first aim of this research work was the determination and evaluation of the bond behaviour under monotonic/static loading. In further investigations, also the bond behaviour under cyclic/dynamic loading will be investigated in order to find values for the creep displacement factors for self-compacting concrete.

Fig. (7) shows the analytical bond stress-slip relationship for monotonic loading according to Model Code MC 90.

4 OWN INVESTIGATIONS

4.1 Mix Design

At present three different concepts for the production of SCC are distinguished (table 1). In contrast to NC for the production of SCC the powder content is increased (Powder-Type), a viscosity-agent is used (Viscosity-Agent-Type) or both possibilities are combined (Combination-Type). In comparison to NC all concepts work with an increased amount of superplasticizer [1].

For this investigation a powder-type was chosen. Therefore, the following mix components were used (table 2). The factors in table 2 refer to the cement content.

4.2 Pull-Out Tests

The bond behaviour for monotonic loading was tested with pull-out specimens which were modified RILEM specimens [2]. The modification was necessary to get a reusable specimen, which has also reasonable costs for production and maintenance. Another advantage of the chosen specimens was to have an uniform concrete cover around the whole reinforcing bar. The bar diameter for the whole test series was 10 mm. Therefore, the specimens had a diameter of 10 cm and a length of also 10 cm. To avoid an unplanned force transfer between the reinforcing bar and the concrete in the unbonded area, the rebars were encased with a plastic tube and sealed with a highly elastic silicone material. The rebars were placed concentrically and the concrete was cast parallel to the loading direction. The tests were carried out in an electro mechanic testing machine where the specimens were loaded path-controlled. The loading rate was 0.0008 mm/sec. The applied force of the machine was measured corresponding to the slip displacement of the reinforcing bar on the non-loaded side. The increase of the slip path was constantly monitored during the whole testing time.

5 TEST RESULTS

5.1 Material Properties

The material properties were evaluated using four standard tests according to DIN 1048:

- cube compressive strength (cube: 150x150x150 mm³)
- cylinder compressive strength (cylinder: Ø150/300 mm³)
- splitting tensile strength (cylinder: Ø 150/300 mm³)
- modulus of elasticity (cylinder: Ø 150/300 mm³)

The specimens were cured in water for 28 days to avoid changes in the curing conditions. Table (3) shows the cube compressive strength and the modulus of elasticity after 28 days of 3 specimens each. This concrete could be classified as B 45 according to DIN 1045. In this standard, the modulus of elasticity for B 45 is 37 000 N/mm². For the tested concrete can be seen, that the modulus of elasticity for the SCC is lower than for conventional concrete; so the SCC is "softer". Schießl [4] obtained the same results. The time development of the material properties is shown in Fig. (8) and Fig. (9). Noticeable is the high early compressive strength and the high splitting tensile strength of the SCC due to the use of fly ash. Such concrete types normally have a slower strength development because of the lower hydration rate of the fly ash.

Therefore, it is difficult to compare the compressive strength with conventional concrete aged 28 days [5]. Within this test series, the material properties will be measured after 56 days. These tests will be carried out in the following time and published in a diploma thesis at the HTWK Leipzig.

5.2 Bond Behaviour

The bond behaviour was measured 1, 3, 7 and 28 days after concreting. Altogether 12 tests were planned; three specimens for each concrete age. Until now, all specimens failed from pulling-out, no visible cracks in the concrete cover were monitored. The results are shown in Fig. (10).

The performed tests show, that the bond behaviour of self-compacting concrete is better than that of normally vibrated concrete.

6 CONCLUSIONS

(1) In this investigation, the time development of the bond behaviour between the reinforcing bars and self-compacting concrete (Powder-Type) was tested under monotonic loading. Depending on the mix design and the modified test specimens it was found out, that the bond behaviour in SCC is better than the correlated bond stresses according to the bond law of König/Tue [3].

(2) In the next step, tests under cyclic loading are prepared. Therefore, different ranges of steel stresses and loadings shall be provided in order to obtain creep displacement factors for self-compacting concrete.

(3)To compare the results found for the dynamic loading, tests with normally vibrated concrete, with vibrated concrete which has a large amount of sand, as well as with SCC are planned.

(4)When self compacting concrete becomes so widely used that it is seen as "standard concrete" rather than a "special concrete", we will have succeed in creating durable concrete structures that require very little maintenance work

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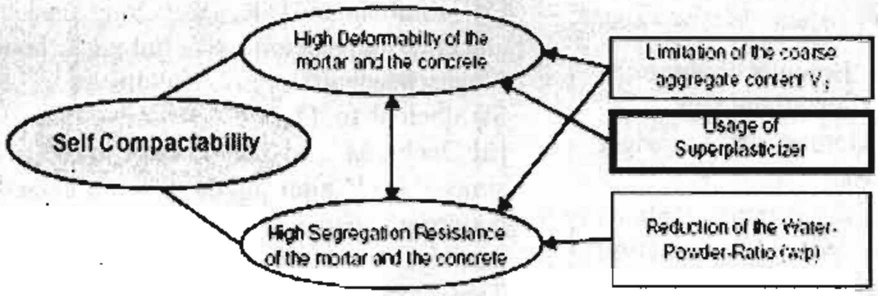


Fig. (1) Basic principles for the production of self compacting concrete

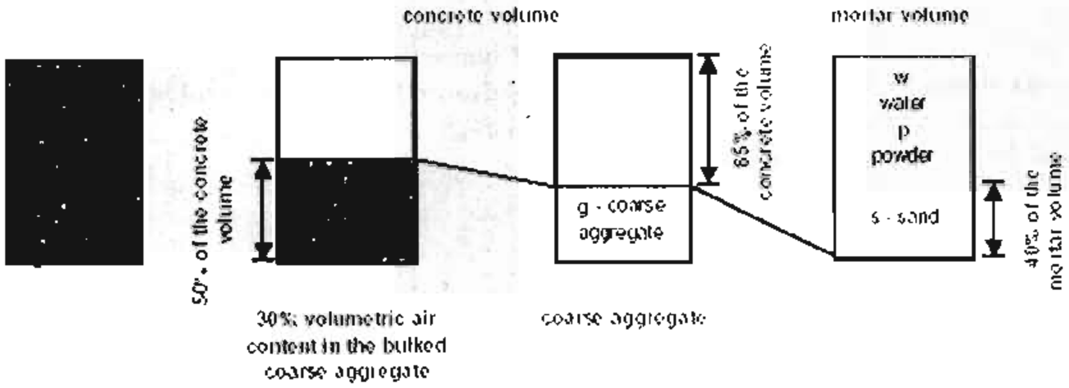


Fig. (2) Determination of the mix components of SCC

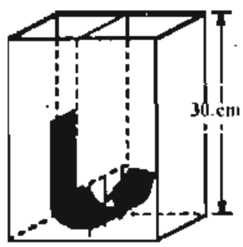


Fig. (3) Box test with obstacles R1 and R2

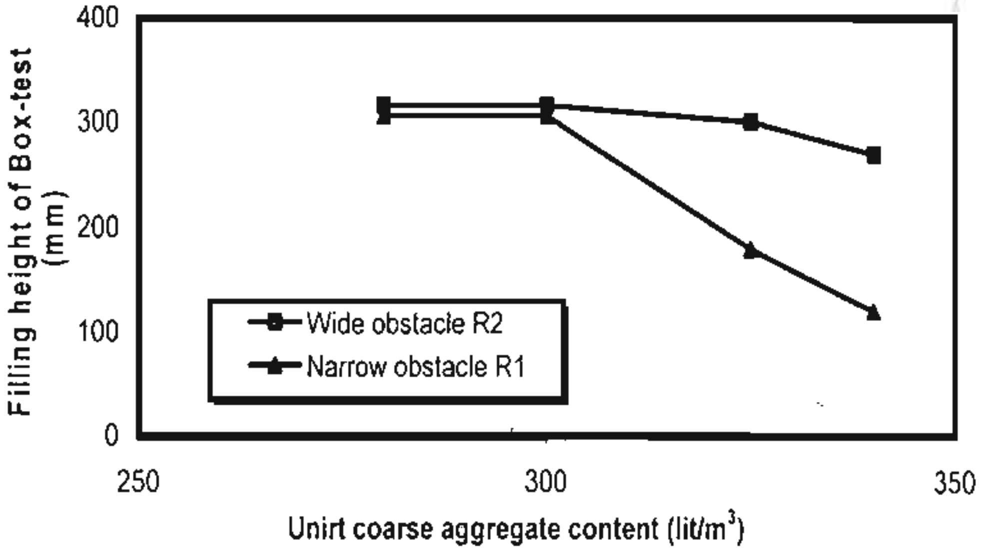


Fig. (4) Influence of coarse aggregate content on self compactability

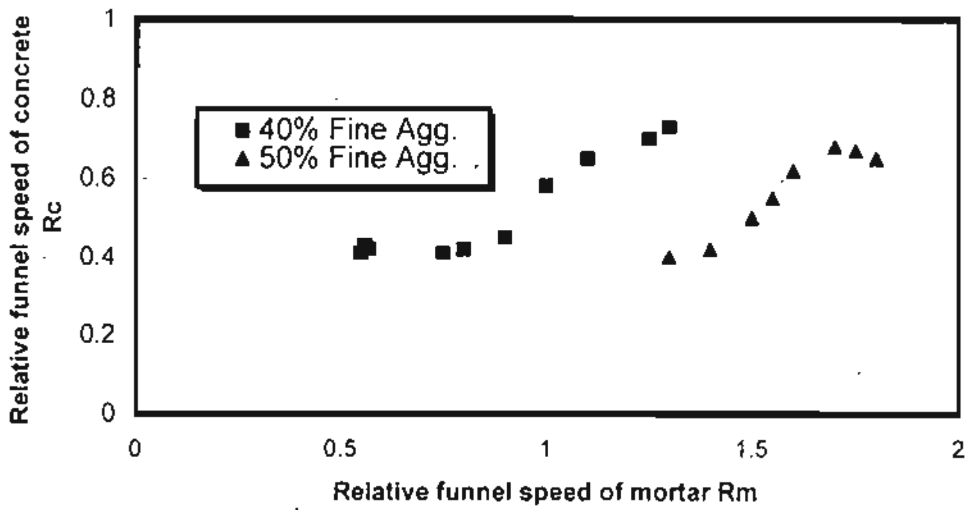


Fig. (5) Relationship between mortar's and concrete's flowability (V65 funnel)

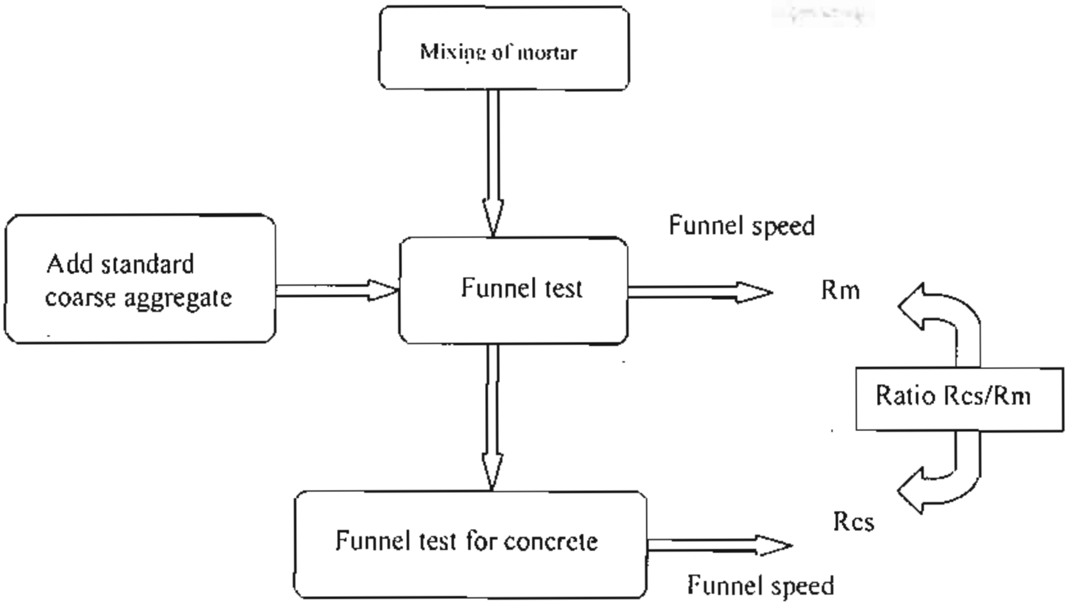


Fig. (6) A simple evaluation method for stress transferability of fresh mortar

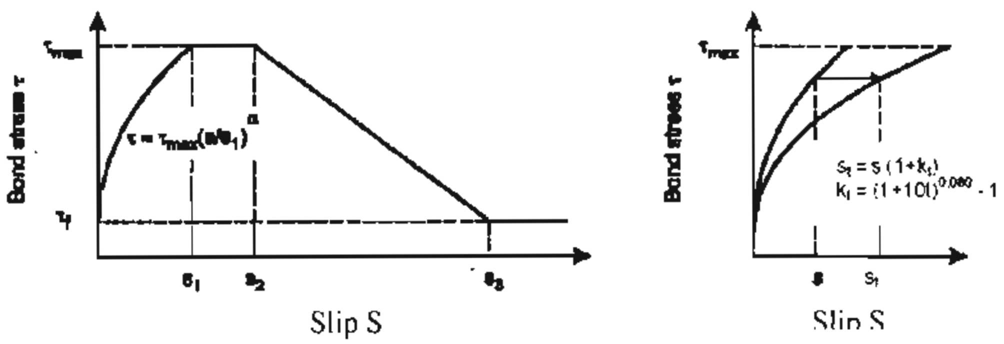


Fig. (7) Analytical bond stress-slip relationship according to MC 90

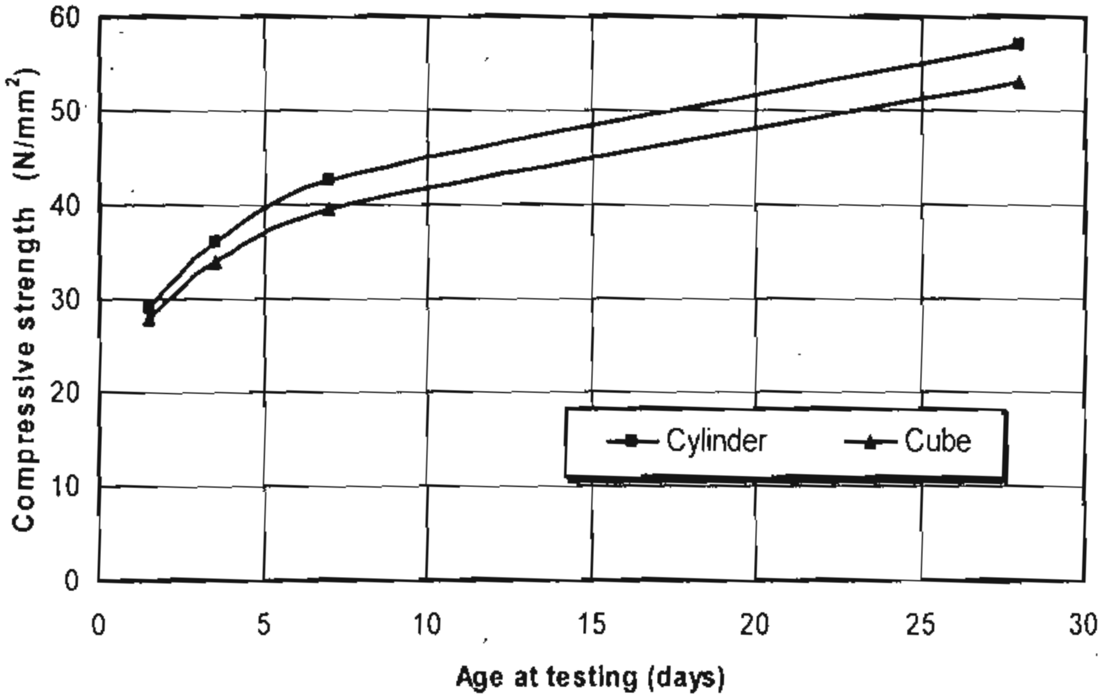


Fig. (8) Time development of the cube and the cylinder compressive strength

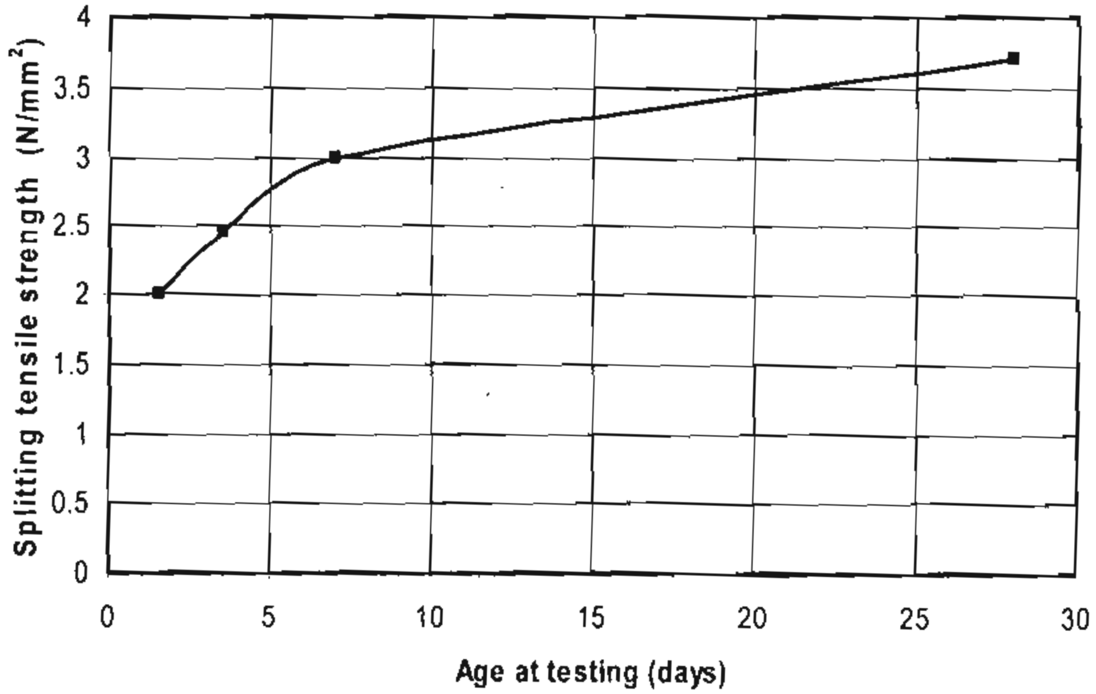
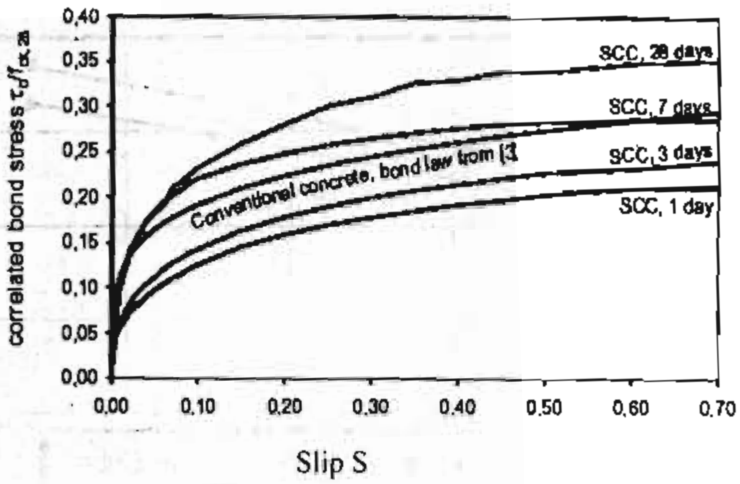


Fig. (9) Time development of the splitting tensile strength



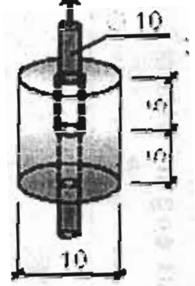


Fig. (10) Time development of the experimental bond stress-slip relationship.

Table (1) Different concept of SCC.

(1)	Powder type
(2)	Viscosity- Agent type
(3)	Combination type

Table (2) mix design or the used SCC.

Cement	1.0
Fly ash	0.67
Quartz powder (0.1-0.4 mm)	0.21
Sand (0-2 mm)	2.43
Gravel (2-8 mm)	0.41
Gravel (8-16 mm)	2.09
Superplasticizer (polycarboxylatether)	0.01
w/b ratio	0.41

Table (3) mechanical roperties after 28 days

Cube compressive strength	(N/mm^2)	56.17	55.25	54.81	55.41
Modulus of elasticity	(N/mm^2)	29190	29754	31217	30100